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DROP/GAS INTERACTIONS IN DENSE SPRAYS

(AFOSR Grant No. F49620-99-1-0083)

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SUMMARY/OVERVIEW:

Turbulence generation and liquid breakup are being studied due to their relevance to dense combusting sprays found in propulsion systems. Turbulence generation is the main source of turbulence in dense sprays; it consists of drop wake disturbances embedded in a turbulent interwake region. Both regions are unusual compared to conventional fluid flows: the drop wakes are laminar-like turbulent wakes typical of intermediate Reynolds number wakes in turbulent environments; the turbulent interwake region consists of isotropic turbulence in the little-studied final decay period. Work already completed has resolved the properties of the turbulent interwake region and overall flow properties for monodisperse particle (drop) flows; current work is addressing these properties for more practical polydisperse particles (drops).

Primary and secondary liquid breakup are important because they are the rate-controlling processes of dense sprays and fix initial conditions for dilute sprays. Past work has shown that liquid breakup should be treated as a rate process and has provided the temporal properties of secondary drop breakup at large liquid/gas density ratios based on experiments. Current work is considering drop deformation and breakup based on time-dependent numerical simulations, emphasizing conditions where liquid/gas density ratios are small and effects of liquid viscosity are large, which are important for practical applications but are difficult to consider using experiments.

TECHNICAL DISCUSSION:

TURBULENCE GENERATION. Early studies of turbulence generation (drop or particle-generated turbulence) showed that these flows were not typical of conventional turbulence (Parthasarathy and Faeth 1990; Mizukami et al. 1992). Subsequently, Wu and Faeth (1994, 1995) studied the properties of particle wakes for turbulence generation conditions and found that they scaled like laminar wakes but with enhanced mixing due to the presence of turbulence, and called them laminar-like turbulent wakes as a result. Work under the current grant then showed for monodisperse particles that the flow consisted of laminar-like turbulent wakes embedded in a turbulent interwake region, that the turbulent interwake region consisted of isotropic turbulence in the rarely observed final-decay period defined by Batchelor and Townsend (1948), that turbulence is sparse in the final-decay period yielding several unusual properties (unusually large rates of dissipation, unusually large ratios of macro-to-micro-scales in spite of small turbulence Reynolds numbers (less than unity), and decreasing ratios of macro-to-micro-scales with increasing Reynolds number rather than the opposite behavior observed for conventional turbulence), and that overall flow properties could be simulated accurately based on conditional averages of the newly resolved properties of laminar-like turbulent wakes and the turbulent interwake region (Chen and Faeth 2000, 2001; Chen et al. 2000).

Current work is considering the properties of flows caused by turbulence generation for more practical polydisperse particle flows (Lee et al. 2001). Measurements and predictions of streamwise relative turbulence intensities resulting from turbulence generation due to monodisperse and binary particle distributions in gases are illustrated in Fig. 1; the comparison between measurements and predictions is excellent with the polydisperse flows handled reasonably well using mixing rules based on the theory. Typical measurements of streamwise PDF's of streamwise velocities for binary particle flows are illustrated in Fig. 2; the unusual form of these PDF's is caused by effects of mean streamwise velocities in particle wakes because these disturbances are included with the turbulence because wake arrivals are random. Work in progress seeks to resolve the moments, PDF's, spectra and scales of the interwake region, the structure of the laminar-like turbulent wakes, and the properties of the overall flow for turbulence generation due to practical polydisperse particle flows.

SECONDARY BREAKUP. Past experimental studies have found secondary drop breakup regimes and outcomes (Hsiang and Faeth 1992, 1993, 1995), have shown that secondary breakup should be treated as a rate process (Faeth 1996), and have resolved the temporal properties of secondary breakup (Chou et al. 1997; Chou and Faeth 1998; Dai and Faeth 2001). These results were limited to breakup processes at normal pressures (where liquid/gas density ratios are large and effects of liquid viscosity are small). Current work is seeking to address liquid breakup properties at high pressure conditions typical of combusting sprays in propulsion systems, where liquid/gas density ratios and effects of liquid viscosity are large. These conditions are being addressed using time-dependent numerical simulations because they are difficult to reach with experiments.

Initial computations considered the problem of round liquid jet breakup in uniform crossflow which is the planar analog of axisymmetric drop breakup due to a shock wave disturbance. Recent measurements of deformation and breakup of such jets, due to Mazallon et al. (1999), are being used to evaluate the computations. An important finding of these measurements is that round liquid jet breakup in a uniform crossflow is qualitatively similar to secondary drop breakup. A typical prediction of the continuous phase properties of this flow is illustrated in Fig. 3 where effects of eddy shedding on flow properties are seen. Evaluation of the present computations using existing measurements yielded very satisfactory results, e.g., for wake sizes, onset of eddy shedding, eddy shedding frequencies, drag coefficients, etc.

Given successful evaluation of the predictions, they were used to find liquid jet breakup properties. The traditional secondary breakup regime map for drops due to Hinze (1975) was not effective for these results because regime boundaries were significantly affected by liquid gas viscosity ratios when effects of liquid viscosity were large. A better approach was to account for liquid viscous effects directly by plotting the ratio of drag forces to liquid viscous forces, $We^{1/2}/Oh$, as a function of the ratio of surface tension to liquid viscous forces, Oh^{-1}, where We and Oh are the Weber and Ohnesorge numbers of the flow. These results are illustrated in Fig. 4. The approach shown yields breakup regime boundaries that are relatively independent of liquid/gas density and viscosity ratios and are in excellent agreement with the measurements of Mazallon et al. (1999). The computations show that increasing liquid viscosity stabilizes the liquid jet to breakup by impeding the rate of deformation of the jet. Work in progress is considering numerical simulations of secondary drop breakup to both shock wave and gradual disturbances, but continues to emphasize small liquid/gas density ratio and large liquid viscosity conditions of particular interest for combusting sprays found in practical propulsion systems.

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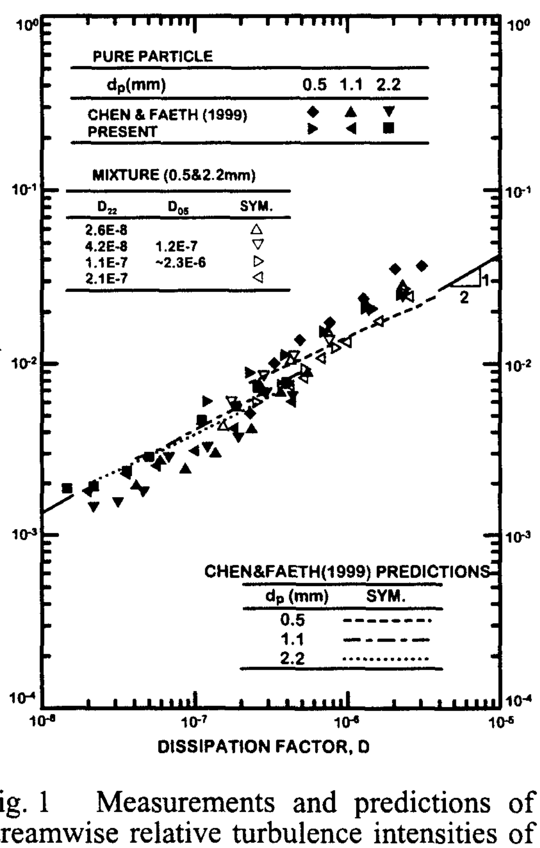

Fig. 1 Measurements and predictions of streamwise relative turbulence intensities of the overall flow as a function of dissipation factor for monodisperse and binary particle flows. From Lee et al. (2001).

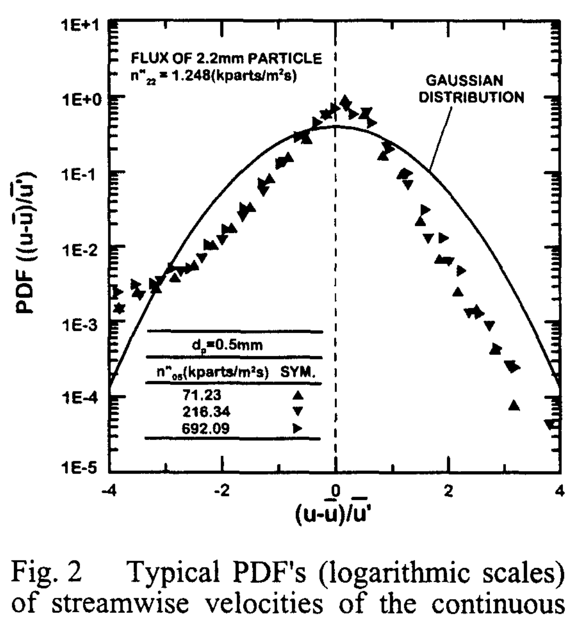

Fig. 2 Typical PDF's (logarithmic scales) of streamwise velocities of the continuous phase for bimodal mixtures of 0.5 and 2.2 mm nominal diameter particles. From Lee et al. (2001).

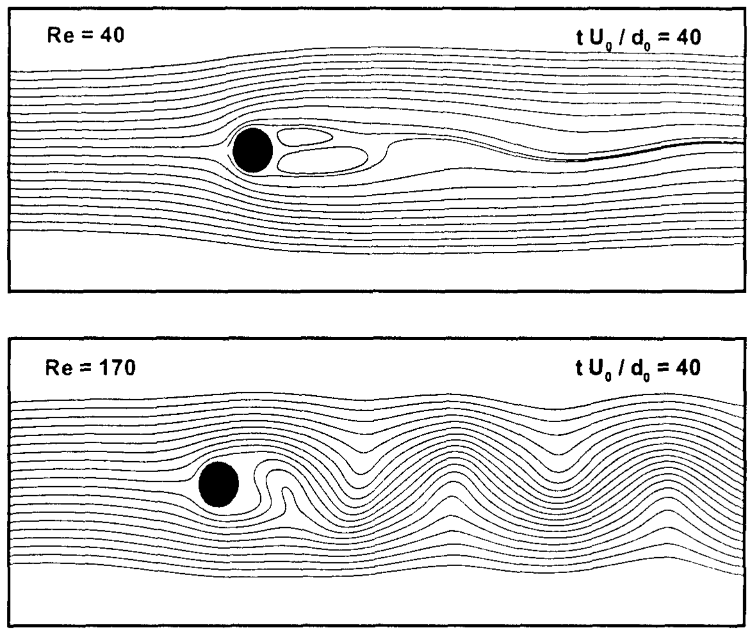

Fig. 3 Streamline patterns for eddy shedding behind a circular cylinder in crossflow for Re = 40 and tU_o/d_o = 40. From Aalburg et al. (2001).

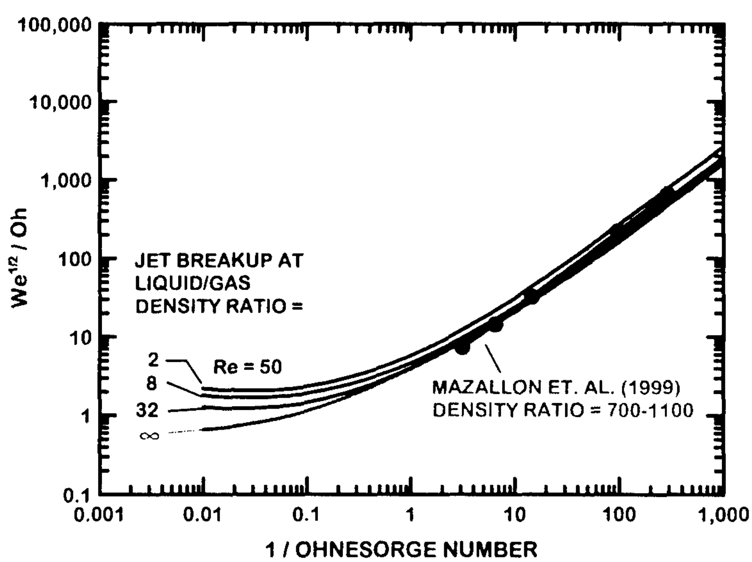

Fig. 4 Breakup regime map for nonturbulent round liquid jets in crossflow plotted according to the large Ohnesorge number limiting form. From Aalburg et al. (2001).